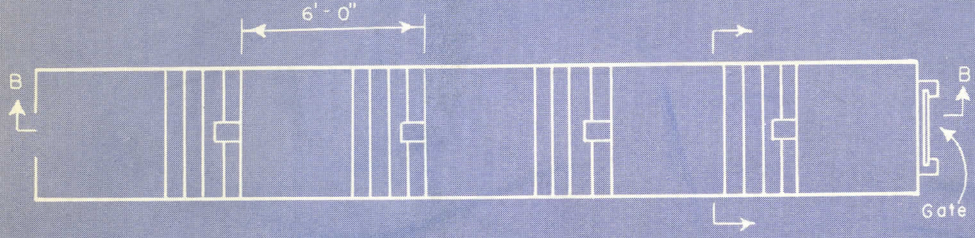
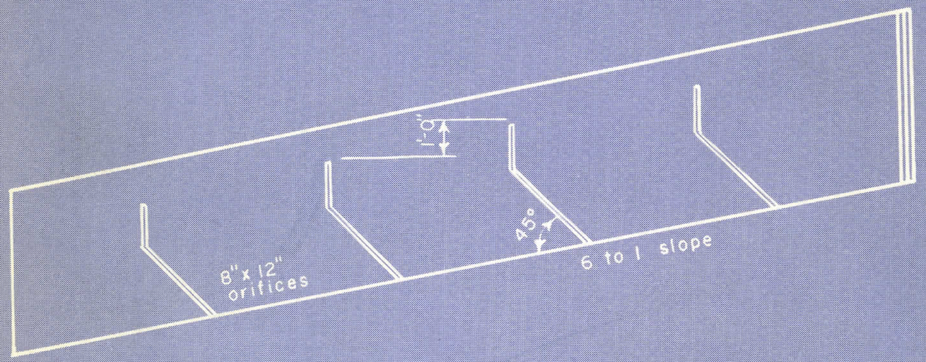
1967

Fishways in Maine, 1967

Maine Department of Inland Fisheries and Game



Fishways in Maine



STATE OF MAINE

DEPARTMENT OF

INLAND FISHERIES AND GAME

FISHWAYS IN MAINE

By

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CONTENTS

The Development and Design of Fishways

The early colonists in Maine first settled along the coast and larger rivers, then moved up the smaller rivers and streams to take advantage of water transportation and to find sites for dams where water power could be used to operate saw and grist mills. Streams were clear and cool, and fish were abundant, particularly in the spring when great runs of Atlantic salmon, shad, and alewives ascended rivers and streams to return to spawning areas. These sea-run fish, called anadromous fish by biologists, were an important source of food and revenue, and large quantities were shipped to city markets outside the state.

It was early noted that salmon, brook trout, and brown trout spawn in swiftly running streams with gravel bottoms, shad in deep riffle areas, and alewives in the quiet waters of ponds and lakes. It was further observed that these fish always returned to the same waters to spawn, and if a stream was dammed so that fish could not ascend to the spawning areas, the run of fish would cease in a few years.

The curtailment in the numbers of fish because of the damming of a few smaller streams was not serious at first; but when main rivers were dammed and sea-run fish disappeared from whole tributaries, there was a public outcry and demand that something be done about it. In what is now the town of Benton on the Sebasticook River, a 12-foot-high dam was built in 1809 with no fishway. The fisheries were so curtailed that after five or six years the town removed the structure. Following its removal, the fish runs increased rapidly, and each resident of the town of Clinton, which then included Benton, was given 200 fish yearly by the town Fish Committee. The town also netted several hundred dollars a year from the sale of the balance of the catch.

At one time, over 3,000,000 pounds of shad were taken from Maine rivers, along with tons of alewives and salmon. In 1825, the St. Croix River was dammed near Calais; in 1830, the Penobscot River was dammed at Old Town; and in 1837, the Kennebec River was dammed at Augusta. Notwithstanding the provisions of the legislative charter authorizing the Augusta dam and calling for an adequate fishway, none was built; and this river and its tributaries, like the St. Croix and the Penobscot, were closed to Atlantic salmon, shad, and alewives. Other Maine rivers suffered a similar fate, and sea-run fish all but disappeared from the principal rivers. Only with the recent construction of efficient fishways have Atlantic salmon and alewives begun making a comeback. Shad are seldom seen.

At a very early date, the importance of developing some method to pass fish over impassable dams was recognized, and by 1787, hydraulic structures called fishways were being developed. The success of these early fishways is doubtful, and few were built. In the early 1860's, a Fish Commission was established by the legislature to seek ways of improving fishing. Considerable emphasis was placed on fishways, and various designs were tried in an attempt to find one that was successful. It was found that fish could seldom ascend sluices in dams, such as are used for logs, because the velocity of water was too great and there were no places for fish to rest. Likewise, a hole near the bottom of a dam produced velocities much greater than the swimming ability of fish could cope with. Some fishways were formed by making rocked-up pools arranged one below the other, such as still can be seen at Damariscotta Mills.

The earliest fishway for which we have a design was called the **Foster type**, after the commissioner responsible for its use, and is shown in Figure 2A, Appendix C. This fishway consisted of a series of vertical baffles placed diagonally and staggered across a sloping channel leading from headwater to tailwater, with a vertical opening left between the upstream end of each baffle and the channel wall.

The commissioners' report of 1867 is optimistic in its description of this fishway; but in 1872, Commissioner Charles G. Atkins reported that alewives and shad were not always successful in negotiating the Foster type, and he requested a legislative appropriation of $1,000 to cover the expenses of professional aid and experiments.

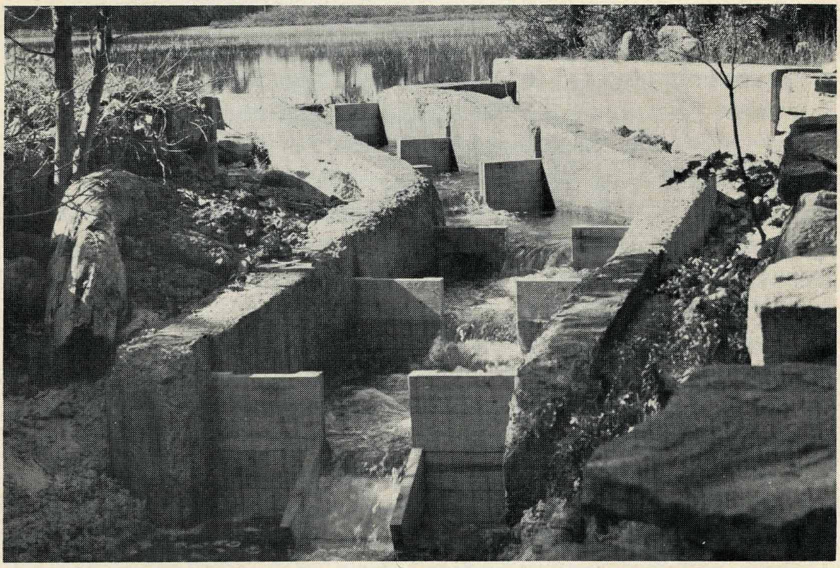
Another early fishway, possibly developed with professional help, is shown in Figure 2B, and is called the **hook type**. A few of these are still in use. One can be seen near the mouth of the Orland River at Orland, another at the outlet of Lambert Lake near Vanceboro. Although this design is not efficient, it does pass fish when properly installed. Its weaknesses are excessive turbulence and lack of resting areas.

About 35 years ago, the Department of Inland Fisheries and Game, successor to the old Fish Commission, engaged a full time professional engineer to design and supervise the construction of fishways, fish hatcheries, dams, and other structures connected with the conservation program. Since that time, many new and improved fishways have been designed and built.

In 1939, the Department obtained the services of a fishery biologist. Following World War II, additional biologists were hired and the Fishery Research and Management Division organized. The biologists have been engaged in surveying lakes and streams, classifying the waters as to fishing population and potential, locating dams and natural obstructions to fish migration, and making recommendations for fishways where they are needed to maintain or restore a run. In determining the need for a fishway, they are guided by the Fishway Policy set forth in Appendix A.

Not all dams require fishways, nor will fishways completely restore fish to their former abundance in all cases. Dams have inundated many miles of riffle areas where trout and salmon spawn; and the impoundments, along with cultivation and deforestation, have caused water temperatures to rise and led to a proliferation of warm-water fish that compete with game fish. Pollution on some streams deter many migrating fish, and the accumulation of solids from saw mills, starch factories, pulp mills, and other sources may destroy spawning beds and nursery areas and remove the life supporting oxygen from the water. Dams, even with well designed fishways, may form a partial barrier to migrating fish, and a series of dams on a river may destroy its value for spawning purposes. Not every fish will find a fishway entrance, and some of the weaker ones may fail to negotiate it. Impoundments behind dams, with the resulting rise in water temperatures, are likely to become the habitat of warm-water fish, such as pickerel, that feed on young fish returning to the sea. Many of the fish that survive these predators are killed going over high dams or through turbines.

The fishway has been most successful in restoring a run of desirable fish when installed in a dam at the outlet of a lake or in the smaller, pollution-free coastal streams containing few dams. A fishway is desirable in a dam at a lake outlet when the lake provides good habitat for landlocked salmon and trout and when spawning and nursery areas are below the dam. Without a fishway, neither the adult fish nor their young could return to the lake. Where lakes are used by spawning alewives, these fish, of



A fishway is desirable in a lake outlet dam when the lake provides suitable habitat for landlock salmon and trout, and good spawning areas are below the dam. (Great Pond, Mount Desert — Pool and weir type fishway)

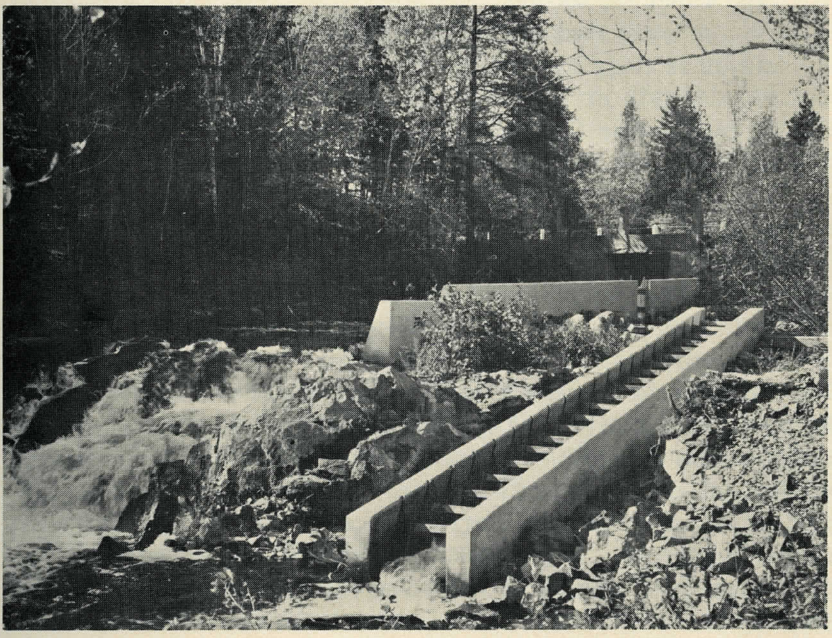
course, must have access to them. Sea-run fish have made an excellent comeback in coastal streams that have been opened to their migration, since it has been relatively easy to install fishways in the few low-head dams. The fish, fresh from the sea, are still strong, and there is little or no pollution to deter them.

The many factors that must be considered in recommending and designing fishways emphasize the importance of the work of the fishery biologist and engineer in carefully investigating each situation. When a fishery biologist determines that a dam or other obstruction prevents migrating fish from reaching useful spawning waters, he asks the Department engineer to make a joint examination with him. The biologist, with his knowledge of the stream and its fish, gives the engineer information concerning the species and numbers of fish that can be expected in the stream, the time of migration, their probable route at the site of the obstruction, and where they tend to congregate. The engineer — then or at a later date — makes a detailed examination and survey at the site, as outlined in Appendix B. With this information, he designs a fishway, estimates its cost, and reports his findings to the Commissioner of the Department. The Commissioner decides whether the evidence justifies a fishway, how it is to be financed, and who is to build it. If the obstruction is a privately owned dam, he may, under Maine law as set forth in part in Appendix A, require its owner to construct the fishway at his expense. If the estimated cost appears excessive in relation to probable improvements in the fishery, he may decide not to require its construction.

Frequently, a fishway is necessary at impassable waterfalls or in a Department-owned dam. In this case, the cost of construction falls on the Department, and the fishway is built by one of its construction crews or under contract.

Some of the more important criteria considered in fishway design may be summarized as follows:

1. The fishway entrance should be as close as possible to the point where fish naturally congregate in their upstream migration.
2. Entrance flow must be strong enough to attract fish into the entrance of the fishway.



Often a fish passage facility is necessary at natural barriers such as an impassable falls. (Cathance River, Marion Township — Denil type fishway)

3. When fish swim from a pool or resting area through an area of high velocity into another pool or resting area, they should be required to make as little change in direction as possible.

4. Resting areas, with water velocities reduced to about 1 foot per second, should be provided for approximately every 8 feet of vertical rise or where there is an abrupt change in the fishway alignment.

5. Energy dissipation must be complete so that there will be no carry-over velocities from one segment or pool of the fishway to another.

6. Depth of water within the fishway must be sufficient to provide ample swimming and resting space. Two feet should be considered the minimum; more is desirable.

7. The flow pattern must be stable without excessive turbulence.

8. Velocity of flow at the entrance should be from 3 to 6 feet per second, and in corridors about 2 feet per second.

9. Maximum velocities within the fishway should not exceed 4 feet per second.

10. A trash rack should be installed at the fishway exit to minimize clogging from debris.

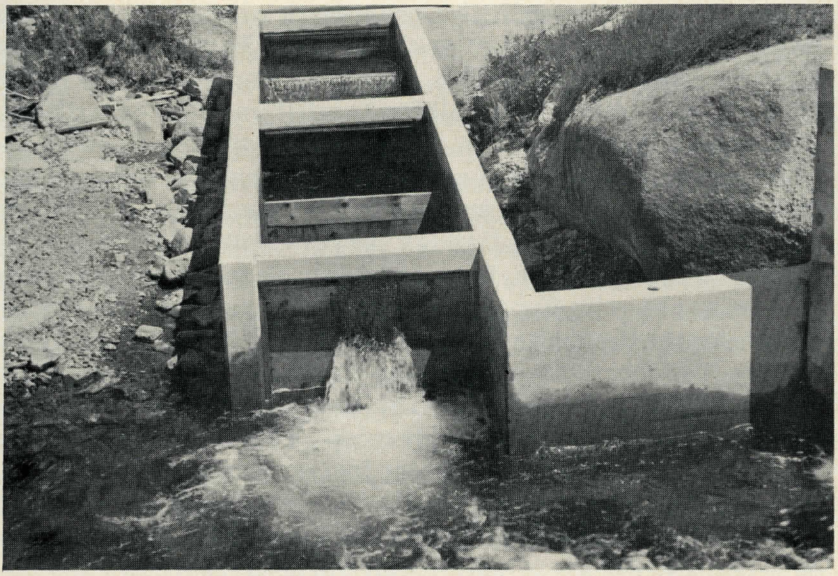
11. A gate or stop logs should be installed near the exit to control the flow of water and to permit closure for inspection and repairs.

12. A gate or stop logs should be installed at the fishway entrance to control entrance velocities.

13. The fishway exit must be so located that emerging fish will not be swept back downstream.

14. The fishway must be accessible for inspection, cleaning, and repair.

The most important factor in the success of a fishway is its location, particularly that of its entrance. Fish, when ascending a stream, tend to follow the stronger current in the main body of water and continue until they are prevented from ascending further by an impassable barrier, such as a high dam, or by too strong a current. If the obstruction is a dam or waterfall, the fish congregate at its foot before seeking a way around it. The fishway entrance should, therefore, be located as close as possible to the point of concentration. This is usually at the point of main water attraction which, at a dam, may be at the spillway, sluice-



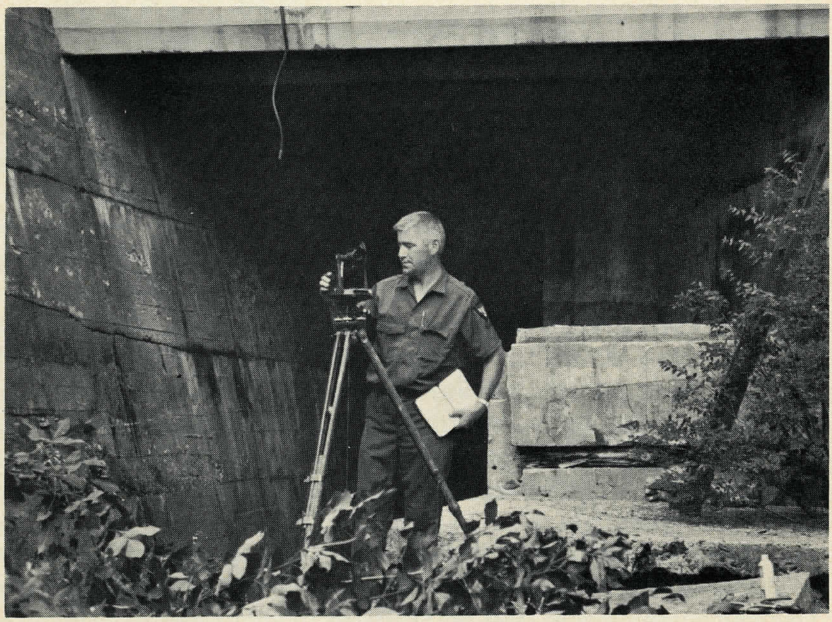
The fishway entrance should be located near strong current and the main attraction point for the fish. (Cold Stream Pond, Enfield — Pool type fishway)

way, or powerhouse tailrace. It is necessary for the fishway engineer to determine where this main flow is during the periods of fish migration, and changing flow patterns may require more than one fishway entrance.

Where a dam contains only a spillway and sluiceway, as shown in Figure 1A, the fishway should, if possible, be located between the two and may require two entrances. Where a dam contains only a spillway, as shown in Figure 1B, the problem becomes more difficult, particularly if the dam is long, for fish may be widely distributed along the toe of the dam and thus not find the fishway entrance as readily. For this reason, it is even more important to determine the channel used by fish swimming up the stream to the dam in order to find the best location for the entrance.

Sometimes it is possible to lower slightly a portion of the dam adjacent to a fishway in order to divert more water past the fishway entrance and thus attract fish to that spot.

A common situation requiring a fishway is at a dam used for hydroelectric power. During periods of peak flow, such as occur during the spring runoff, fish congregate where water is being spilled at the toe of the dam or sluiceways. During drier periods when no water is being spilled, they congregate below the power plant. This situation may call for two fishways or one with two entrances. Sometimes it is possible to locate the fishway between the power plant and a sluiceway so that the entrance will be near both the tailrace and the foot of the sluiceway. Where most of the water passes through the power plant during a major portion of the migration, it may be desirable to locate a **collecting gallery**, as shown in Figure 1C, along the downstream face of the plant over the discharge in order to collect fish swimming up the tailrace. Such a collecting gallery requires auxiliary water, in addition to that furnished by the fishway, in order to provide a strong flow at the gallery entrances. This is usually provided by running a pipeline from a point just above the dam to a diffusion chamber below or beside the collecting gallery. If at all possible, a collecting gallery should be constructed at the same time the power house is built in order to keep costs down and prevent possible shutdown of the power station.



A Department engineer surveys for fishway construction at a hydro-electric dam. (Penobscot River, Milford)

Figure 1D shows a dam where most of the flow is through a sluiceway; hence, the fishway entrance is located close to it.

Once a location has been decided upon, a decision must be made as to the type of fishway to be built and the materials to be used in its construction. The type will be determined by the size and flow of the river, the fluctuation in water levels, and the species and quantities of fish using the stream. The materials used will be determined in part by the materials used in the dam, the size of the structure, the importance of the fishway, and the availability of funds. For the more important and larger fishways, especially those that must withstand the impact of flood waters, ice, and logs, reinforced concrete is the most suitable material for the main fishway, with timber commonly used for the interior weirs and baffles. Timber fishways are usually installed in low-head dams made of timber, since there is no point in building the fishway of more durable material than the dam. The useful life of a timber fishway is limited to about 10 years.

The water discharging from a fishway attracts fish to its entrance, and this attraction is determined by the volume and velocity of this water in relation to that discharging over or through the dam. An entrance velocity of from 3 to 6 feet per second is usually provided, and the volume may vary from 2 cubic feet per second (cfs) to 60 cfs or more. For example, if the width of the opening of a fishway entrance is 1½ feet and the depth of water at that point is 4 feet, the area at the point of discharge is 6 square feet. If an entrance velocity of 4 feet per second is required to attract fish, then the required volume, from the formula $Q=VA$, is 4 x 6 or 24 cfs. Since this flow exceeds the capacity of all but the largest fishways, it would be necessary either to reduce the area of the opening at the entrance or to add auxiliary water.

Where the water discharging from a fishway must compete with strong stream or tailrace flows, it may be desirable to add auxiliary water to the entrance pool. A **diffusion chamber** is constructed under or adjacent to the entrance pool or collecting gallery, separated from the pool or gallery by a steel grating of an area sufficient to keep the velocity down to about one-half of a foot per second. A pipeline is laid from the forebay to the diffusion chamber, and the flow of water is controlled by valves. Recent fishways installed in the St. Croix River have this feature.

Second only to the location of the fishway entrance, the most important consideration is the kind of fishway that is to be built and its arrangement. Appendix B lists some of the factors that must be considered in the investigation, location, and design. Where there is but little fluctuation in stream levels, particularly in the forebay, a pool and weir type or a Denil fishway may be used. A moderate fluctuation may be handled by the Denil fishway or a vertical slot type. A greater fluctuation may call for a submerged orifice or a vertical slot type or similar fishway. The following pages describe a number of different fishways, their application, and their advantages and disadvantages.

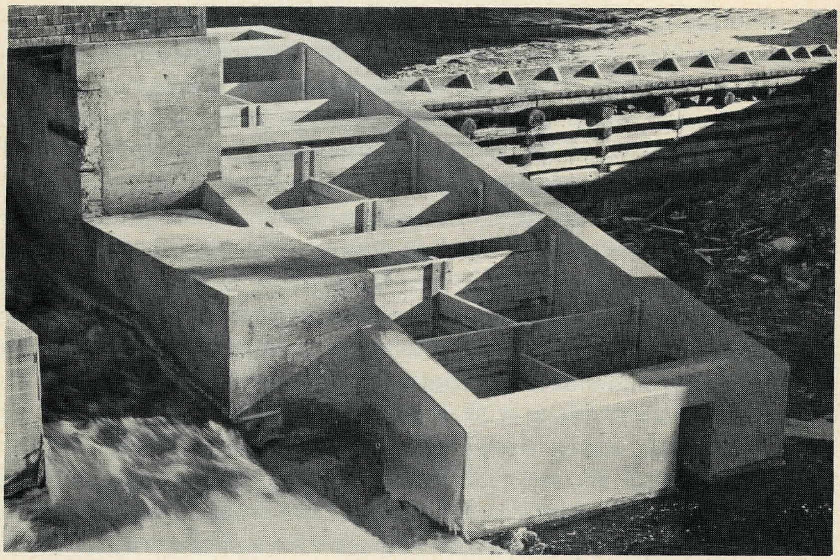
The **pool and weir type** fishway, shown in Figure 3, Appendix C, is one of the oldest and most widely used. Pools are square or rectangular in shape and vary from a width of 4 feet to 10 feet in the east up to a width of 40 feet on the Columbia River. The main flow of water is over the crest of a vertical weir or baffle. The weir may extend the full width of the pool or, more commonly, be notched as shown in the example. In some fishways, the weirs are located in the centers of the baffles; in others they are located on the sides and staggered to minimize carry-over velocities. Depth of flow over the crest of the weirs may vary from a few inches to a foot or more, depending on the size of the pool and the amount of the resulting turbulence. Orifices are provided near the bottom of each baffle to facilitate draining pools and to add to water attraction. The orifices are proportioned to the size of the pools, but are smaller than for a submerged orifice fishway. Water depth should be at least 3 feet, more for large pools, in order to provide proper dissipation of energy and swimming space for fish. For smaller fish, such as brook trout, pools may be 5 or 6 feet square. For fish the size of Atlantic salmon, and on large rivers, pools should be up to 12 feet long and 8 feet wide, with a 1-foot drop per pool, and with notched weirs 3 or 4 feet in width. With a pool depth of 5 feet, staggered 10″ x 12″ orifices should be provided for each baffle in the larger pools. Tables in Appendix D give volume of flows for various weirs and orifices.

The pool and weir type fishway is relatively simple to design and build, and it efficiently passes game fish such as trout and salmon, providing the flow of water is properly regulated. It has the disadvantage of not readily passing shad and alewives, since these fish, although they are strong swimmers, do not usually surmount an overfall or leap over obstacles. A further disadvantage is that this fishway is sensitive to changes in stream levels. If the flow of water over the crest of the weir is changed in depth more than a few inches, particularly if the weir extends for the full width of the pool, the hydraulic characteristics may change completely and deter fish from negotiating the structure. Unless provision is made to by-pass or lower a few of the upper weirs, flow of water over the weirs will cease if the forebay level drops below their crest. A rise in stream level may produce streaming or undue turbulence. Fluctuation in stream levels may be partially controlled if the upper baffles are provided with deep weirs or notches fitted with stop logs or gates that may be regulated in accordance with forebay levels, but this requires an attendant with a knowledge of fishway operation and adds to operating costs. Since the water level in most streams fluctuates considerably, since many dams do not have attendants, and since it is very frequently desirable to pass alewives as well as trout and salmon, not many pool and weir types are designed today.

On longer fishways at high dams used by trout and salmon, it is sometimes practical to modify the pool and weir type by providing balancing pools at the upper end, the number of such pools being twice the headwater fluctuation in feet. Figure 4, Appendix C, shows such a fishway, called a **combination fishway**. In the balancing pools, the entire flow of water is through orifices, these orifices being rectangular openings at the bottom of the vertical partitions separating the pools. It is a principle of hydraulics that with orifices of uniform size, the water level from pool to pool will differ by the same amount. As forebay level rises, the difference in water level between pools will increase; as it lowers, the difference will decrease. Such fishways are designed to provide a maximum pool differential of one foot and a minimum of six inches. The flow through the remainder of the fishway below the balancing pools is over the notched weirs, except for a small amount going through the drainage orifices.

Although the combination fishway may efficiently pass trout and salmon, shad and alewives rarely go through submerged orifices. In spite of trash racks at the head end, orifices are easily clogged and are difficult to get to for cleaning.

The **submerged orifice fishway**, shown in Figure 5, has most of the advantages and all the disadvantages of the combination fishway. It is relatively simple to design and build, and water

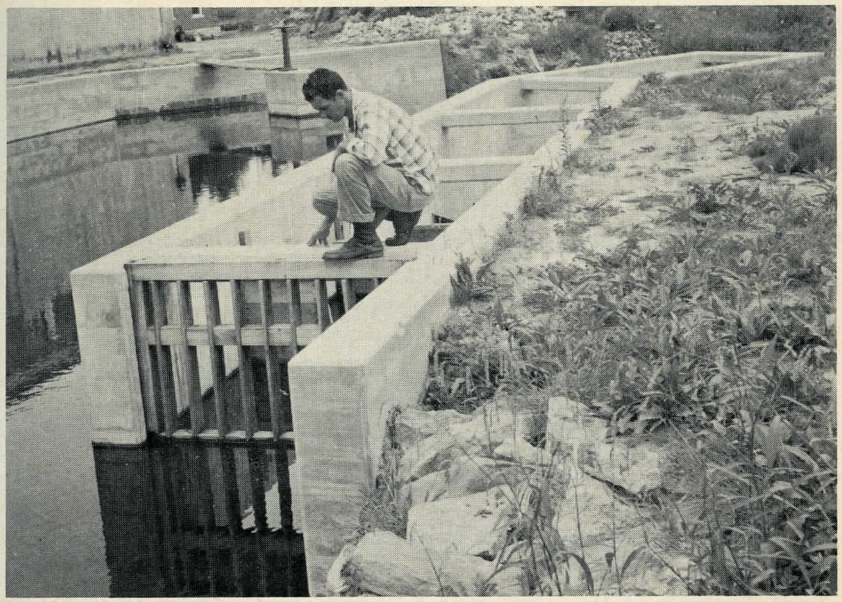


The submerged orifice fishway is often used at lake outlets. (Rangeley River, Oquossoc)

levels balance well from headwater to tailwater. Maximum design differential in pool levels is kept to one foot, with a six inch minimum. A dam with a maximum head of 10 feet would call for a fishway having 11 pools, the entrance pool having a vertical opening extending the full height of the baffle instead of an orifice. With this head, the drop per pool is one foot. If the forebay level should drop so that the head at the fishway became 5 feet, the drop between pools would be 6 inches.

The baffles or partitions separating the pools in a submerged orifice fishway may be either vertical or inclined as shown in Figure 5. When vertical baffles are used, it is desirable to stagger the orifices to prevent carry-over velocities. Orifice sizes may vary from 6″ x 8″ for small pools up to 18″ x 24″ for larger pools. Downstream edges of the orifices are bevelled, and the first orifice at the head end should be made from 25% to 50% larger than the others to minimize the effect of clogging. A trash rack and head gate should, of course, be provided, although not indicated in all of the accompanying sketches.

This fishway has the advantage of self-adjustment without frequent attention, plus the ability to pass trout and salmon.



Fishery biologists and engineers make periodic inspections of fishways. A clogged trash rack or fishway opening can prevent fish from passing. (Branch Brook, Wells)

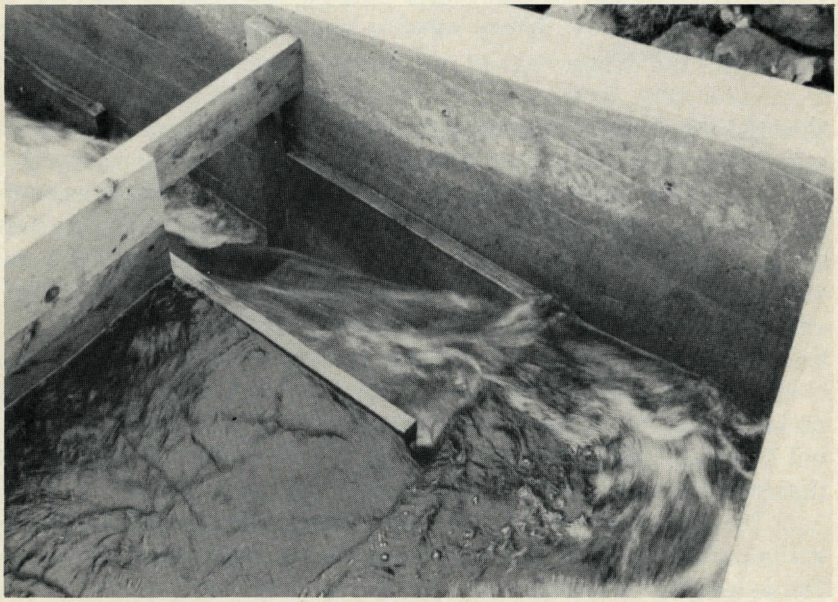
The fishway is most useful at the outlet of many interior ponds and lakes used for water storage and subject to considerable drawdown. In the fall of the year, some of these lakes are lowered to nearly their original level, and this is one of the few designs that will pass fish under these conditions. In this design, careful attention must be given to see that the floor at both ends of the fishway is at least two feet below low water levels so that a flow of water and swimming space is always assured, even during dry periods. As previously pointed out, orifices have the disadvantage of being easily clogged plus the fact that they do not readily pass alewives and shad. This latter fact precludes their use in most coastal rivers.

To overcome some of the disadvantages of the previously described fishways, chutes are sometimes installed in pools for the passage of alewives, one type being shown in Figure 6. The chute eliminates the necessity of fish jumping from pool to pool, as in the pool and notched weir type, or submerging, as in the orifice type, and will thus pass alewives as well as trout and salmon. Since shad runs have almost disappeared from Maine streams, we have not observed this species in our fishways.

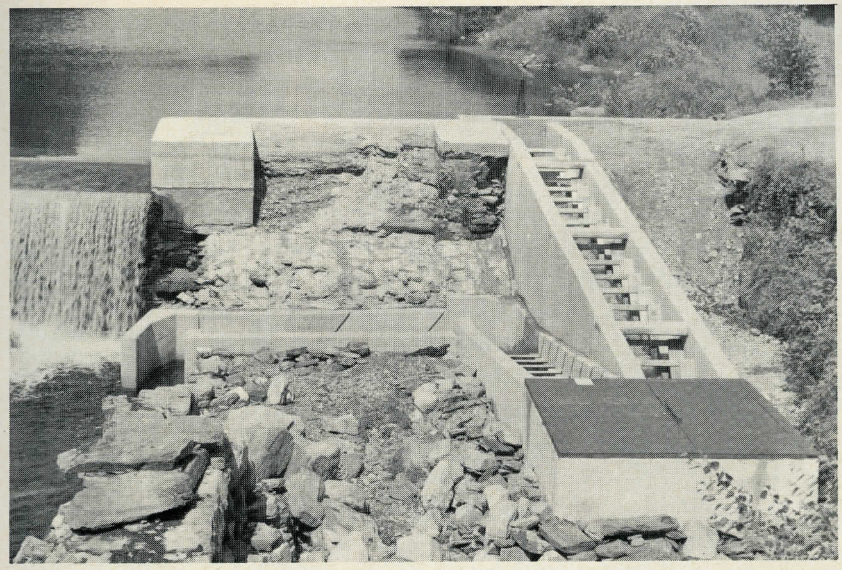
The **chute type fishway** is successful as long as the flow of water is controlled within design limits. It is desirable to install by-pass openings with stop logs in the upper baffles alongside the chutes so adjustment may be made as forebay levels go down; otherwise, the fishway may become inoperative. Small, drainage orifices are installed at the bottom of each baffle as in other pool type fishways. This fishway shares the disadvantage of the pool and weir type in that it is not self-regulating.

Figure 7 shows a modification of the chute type fishway, called the **butterfly weir**. It has essentially the same characteristics and use as the chute type, with similar advantages and disadvantages, except that it will handle a greater range of flows. Both of these types have been largely replaced by the Denil fishway.

Figure 8 shows the **Denil fishway**, a design completely different from the usual pool type and one widely used today. The first fishway of this kind was designed by G. Denil of Brussels,



The chute type fishway was common in the past and some are still in operation in Maine, though none are being built now. (Nequassett Brook, Woolwich)



The Denil type fishway is becoming the most popular fish passage facility in Maine. Its characteristics often meet the state's needs, and the cost is moderate. (Sheepscot River, Cooper's Mills)

Belgium, about 1909. From 1936 to 1938, the Committee on Fish Passes of the British Institute of Civil Engineers carried on further experiments with the objective of developing a simpler design than the complicated baffles proposed by Denil. These investigations resulted in the development of a single-plane baffle having a channel width of 3 feet with spacing of baffles being 2/3 of this width, or 2 feet. Openings between the sloping baffles were made 7/12 of the channel width or 1′ 9″. Effective water depth was from 2 to 3 feet. The British Institute recommended a slope not exceeding five to one for the floor of the channel, with the baffles sloping upstream at a 45° angle to the floor. Resting pools were recommended at vertical intervals of from 6 to 8 feet.

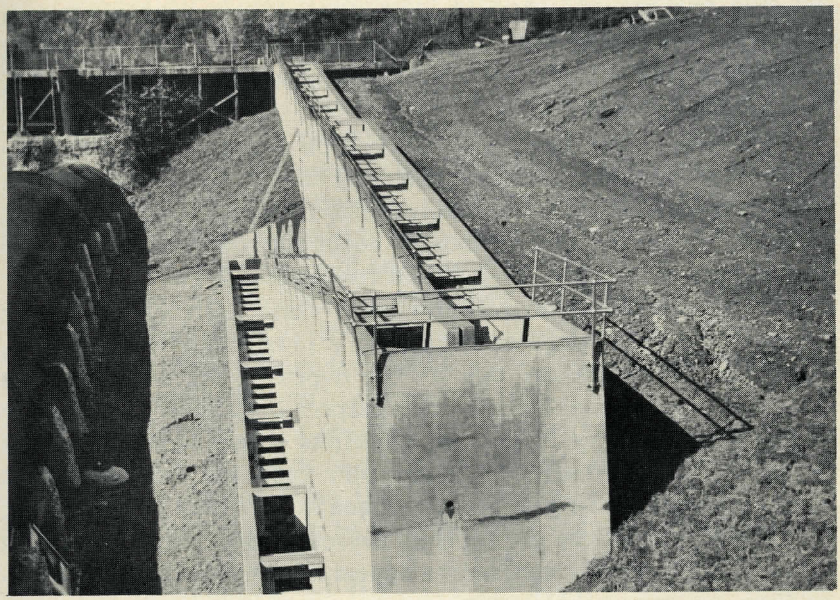
This design was used for a fishway installed in the Herter Dam in Sweden, except that the channel width was made 4′ 3 1/4″, with the baffle spacing being 2/3 of this and the clear opening in the baffles being 2′ 6″. This fishway, completed in 1945, was found to be quite successful in passing Atlantic salmon and trout.

One of the first Denil fishways in this country was installed in 1949 in Dryden Dam, Washington, by the U. S. Fish and Wildlife Service. Comparisons made with a conventional pool and weir type fishway at the same site indicated that the great majority of Pacific salmon used the Denil in preference to the other.

Because of these favorable reports, we designed in 1956 a Denil fishway with a 3 foot channel for installation in one of our low-head dams, the first Denil in the East. This proved so successful that we have since designed and installed more of this type than any other, most being in our coastal streams. Almost all new fishways designed to pass alewives and other anadromous fish are of this type. Channel width has varied from 2 to 4 feet, with the maximum head being 50 feet and the longest channel 745 feet. In all cases, the same proportions of spacing recommended by the British Institute of Civil Engineers has been retained. Most have been built on a six to one slope, but a few have been installed on an eight to one slope. The flatter slopes, of course, produce lower velocities and less turbulence.

The Denil fishway is one of the best all around types so far in use in Maine. It is not the ultimate in fishway design, any more than any other; neither is it suitable for every situation. It has the advantage of handling moderate fluctuations of 2 or 3 feet without adjustment, it is not easily clogged by debris, its hydraulic characteristics are excellent, and all fish with which we are concerned negotiate it well. As with all fishways, very careful attention must be given to the location of its entrance; and, even though it passes up to 20 cfs of water, it may be desirable in some cases to add auxiliary water at the entrance to improve attraction. In general, the floor of the fishway at its entrance and exit should be at least 2 feet below low water levels. Resting pools are installed at turns and on any run exceeding 8 feet in vertical height. Maximum velocities are seldom over 3 feet per second.

Some of the more important Denil fishways built in Maine are those on the Sheepscot River at Cooper's Mills, the Pennamaquan River at Pembroke, the outlet of Alamoosook Lake on the Orland River at Orland, the Machias River at Whitneyville, the Piscataquis River at Howland, the St. Croix River at the Grand Falls powerhouse in Baileyville, and the St. Croix River at Woodland.



This Denil fishway, 745 feet long and with a vertical rise of 50 feet, is the largest of its kind in the eastern United States. (St. Croix River, Woodland)

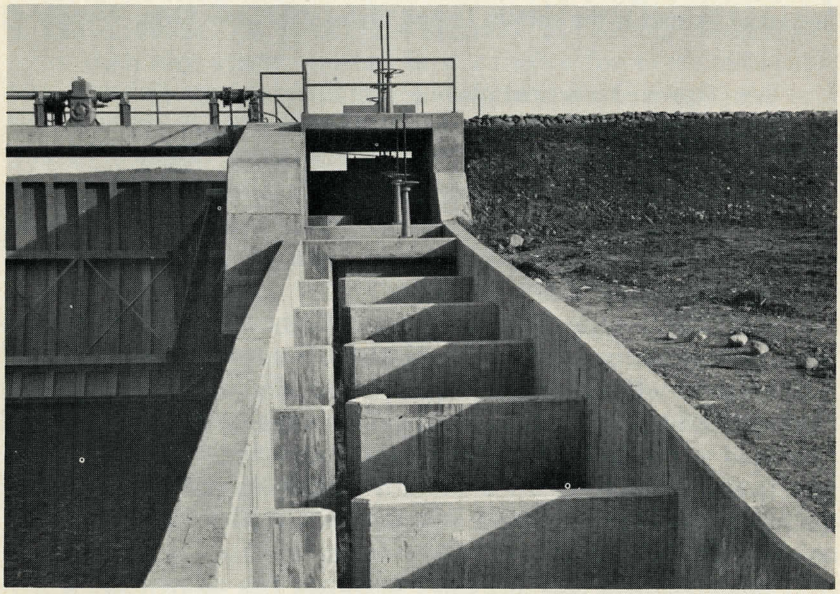
An improved vertical slot or pool and jet type fishway, also called the **Hell's Gate type** after the locality where it was first built on the Fraser River in British Columbia, has been widely used in recent years on the Pacific coast. A sketch of this type of pool is shown in Figure 9. The fishway was developed about 1943 under the direction of Milo C. Bell of the University of Washington.

The Hell's Gate fishway is essentially a pool type with a vertical slot on one side of vertical baffles and extending their full height. Each opening is so shaped that the flow of water is directed diagonally across the next lower pool, then back toward the head end of the fishway for a short distance, before discharging through the next lower slot. Dissipation of energy is complete within each pool, and velocities are well within the swimming abilities of migratory fish.

Most vertical slot fishways designed for salmon are 8 feet wide with pools 10 feet in length. The vertical slots are about 14 inches in width, and the drop per pool does not exceed one foot. For smaller fish, such as brook trout, the pool size may be reduced to 6′ x 8′ with a 10 inch slot, or to 4′ x 6′ with an 8 inch slot. For the small pools, the drop per pool should be reduced proportionately. Materials may be reinforced concrete, timber, or a combination of the two.

To date, only one Hell's Gate type fishway has been designed and built for a Maine dam, and that is for a 14-foot-high structure located near the headwaters of the St. Croix River at Vanceboro. This fishway has 16 pools, each 8 feet wide by 10 feet long, and operates under a 10 foot drawdown.

The great advantage of the Hell's Gate fishway over other types is the wide range of water levels it will handle efficiently, the range being limited only by the depth of the pools and the height of the vertical slot. In this respect it exceeds the capacity of the Denil fishway. Fish may negotiate it by swimming at any depth, it is not a barrier to migratory fish, the fishway is not easily clogged by debris, resting space is provided in each pool, and the large volume of water it passes provides good entrance attraction. Cost of construction appears to be substantially higher than for most other types.



The improved vertical slot or Hell's Gate fishway has many advantages, though construction costs are higher than most other types. (St. Croix River, Vanceboro)

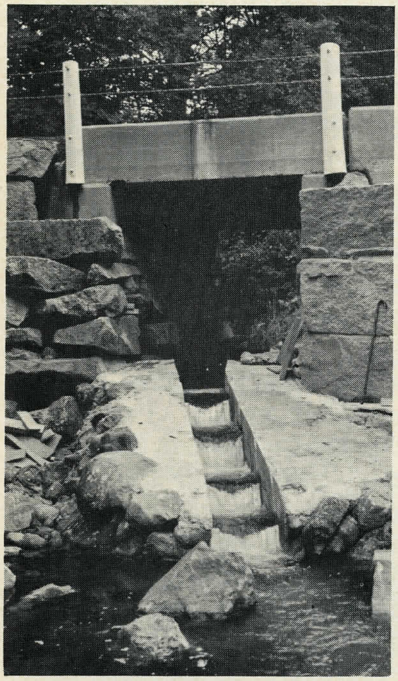
Figure 10 shows a sectional view of the **Borland fish lift.** This is a form of fish lock, working on a principle similar to a ship lock, in which fish are attracted into a collection chamber by a flow of water at its entrance. After a sufficient quantity of fish have entered the chamber, the lower gate is closed, and the passage leading to the exit allowed to fill with water until the fish can swim into the forebay. Vertical cylindrical locks working on the same principal are in use on the Columbia River, along with conventional pool and weir types. There are a number of fish locks in use in Europe, and they are reported to pass all species of fish down to the smallest without undue effort on the part of the fish. Most fish locks have timing mechanisms and work automatically, with electric controls.

No fish locks have been built in Maine, but they might have an application in a high dam if provision could be made for their construction at the time the dam was built. For such dams, the cost should be as low as or lower than for a conventional fishway.

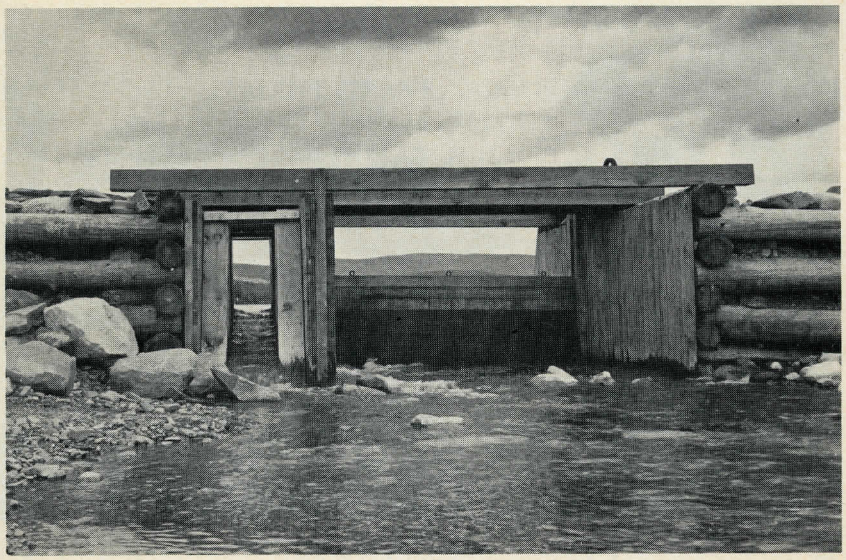
The development of fishways has been a gradual process, and most types have evolved from earlier models. Two **experimental fishways** of the vertical slot type, shown in Figure 11, illustrate this development. The first fishway in Figure 11 has many of the characteristics of the Hell's Gate type except that the diagonal arrangement of the baffles has the effect of lengthening the pools to give better dissipation of energy. The second experimental fishway combines most of the characteristics of the Foster type and the hook type shown in Figure 2. Neither experimental fishway has been built so far, but they are shown to illustrate the need for continual study and experimentation in order to develop improved designs.

There are many factors responsible for the failure of certain fishways to pass fish. These may be classified as improper location, improper design, and improper maintenance.

The importance of location has been stressed already. Many of the older fishways have had their entrance located too far below a dam so that fish by-pass it and congregate at the toe of the dam itself. Others have not had their entrance located near the main flow of water passing over or through the dam, but have been placed too far to one side, while some have had either their entrance, exit, or both located too high above low water levels so that fish could neither enter the fishway nor find sufficient swimming space if they did.



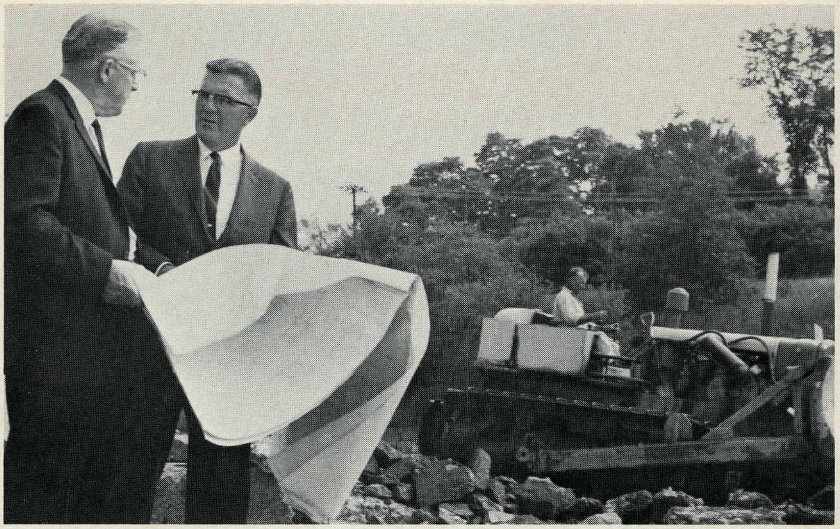
Not all fishways are large or expensive, and often only a minimal investment is required to open large nursery and spawning areas. (V-notch weir type at Batchelor Brook, Sebago, and Denil type at Bryant Pond, Woodstock)



Wooden fishways are built at log dams as it is false economy to build a fishway which will outlive its dam. (Denil type at Embden Pond outlet, Embden)

The most common design error is to make the pools too small or to use weirs that cause excessive turbulence, such as the hook type illustrated in Figure 2B. Some fishways have been installed on too steep a slope, or have not had properly located resting pools. In other cases, the flow of water leaving the fishway is not strong enough to attract fish in competition with flows passing through or over the dam. Another mistake is to save money on construction materials, only to have to rebuild or repair the fishway in a few years.

Good design and construction are not sufficient if the fishway is not properly cared for. The most common causes of fishway failure are faulty maintenance and vandalism. Frequently, some of the passages are clogged with debris. In other cases, head gates have been closed when they should have been open, or stop log controls have been neglected. Many timber fishways have leaks that develop and are not corrected, so that the amount of water in each pool diminishes from the exit to the entrance. Vandals play their part by playing with gates and stop logs, shutting off the flow of water, or even in some cases filling the



The co-operation of dam owners in Maine has been a major factor in the success of the state's fishway projects. Robert N. Haskell, President of Bangor Hydro-Electric Co., and Fish and Game Commissioner Ronald T. Speers inspect construction at a fishway site. (Penobscot River, Milford)

pools with large rocks. Even though the law provides penalties for molesting a fishway, it may be necessary to erect a woven wire fence around the structure to prevent unauthorized access.

Fishery biologists, game wardens, and Department engineers inspect fishways as often as possible, calling the attention of the owners to needed repairs, but the co-operation of the general public is required if fishways are to function properly.

APPENDIX A

MAINE DEPARTMENT OF INLAND FISHERIES AND GAME

FISHWAY POLICY

No fishway will be recommended by the Fishery Division unless it can be reasonably supported before a Justice of the Superior Court. This is necessary to protect the prestige of our Department program in the event that a dam owner should appeal to the courts as provided in Chapter 313 of the Biennial Revision of the Inland Fish and Game Laws, 1965.

Fishways will usually be recommended for the following species of fish only:

1. Atlantic sea-run salmon
2. Landlocked salmon
3. Brook trout
4. Brown trout
5. Alewives
6. Shad

A. Obstructions on lake or pond tributaries

A fishway should be recommended when:

1. The stream contains sufficient usable spawning and/or nursery area above the obstruction for the species being managed to justify the expense of fishway construction and maintenance.

2. The stream provides a migration route for alewives to a lake, pond, or large deadwater area that will appreciably increase the alewife production.

3. The stream is obstructed "for cultivation of useful fish" as provided in Section 2557 of the Eighteenth Biennial Revision of the Inland Fish and Game Laws, Title 12, Chapter 301 to 335 of the Revised Statutes, Effective September 3, 1965.

B. Obstructions on lake outlets

A fishway should be recommended when:

1. The lake contains landlocked salmon or brown

trout and there is sufficient, unobstructed, usable spawning and/or nursery area below the obstruction to justify the expense of a fishway, or where the outlet is a good brook trout stream that may furnish trout to the lake by upstream migration.

2. The lake is a spawning and nursery area for alewives.

C. Obstructions on streams or rivers

A fishway should be recommended when:

1. There is a lack of spawning and/or nursery and/or adult resident area below the obstruction and enough of these necessary areas above the obstruction to justify the expense of a fishway.

2. The water is a migration route for alewives to a spawning and nursery area.

3. The stream is obstructed "for the cultivation of useful fish" as provided under A-3 above.

Maine Law Regarding Fishways

Sec. 13. Construction of fishways and repairs thereto; appeals.

Whenever the commissioner shall deem it expedient, he may require a fishway to be provided, erected, maintained, repaired or altered by the owners or occupants of any dam or other artificial obstruction above tidewater in any inland waters frequented by salmon, landlocked salmon, shad, alewives, or other migratory fish.

Sec. 13-A. Tampering, injuring or destroying fishways.

Whoever without authority from the commissioner tampers with a fishway, closes a fishway to fish migration, introduces foreign objects into a fishway, or damages or destroys a fishway, shall be punished by a fine of not more than $100. (1963, c. 279, Sec. 1.)

APPENDIX B

ENGINEERING INVESTIGATION OF DAMS AND FISHWAY DESIGN

A. Investigation.

1. Name and location of the stream
2. Name and owner of dam
3. Species and numbers of fish that would use fishway
4. Stream characteristics
    a. Width
    b. Depth
    c. Gradient
    d. Volume
    e. Type of bottom
    f. Fluctuation in water levels
    g. Pollution
5. Dam Characteristics
    a. Type of dam
    b. Material of which made
    c. Condition
    d. Principal use
    e. Height
    f. Total length
    g. Length of spillway
    h. Type, size, and location of gates
    i. Position of power plant or other adjoining structures
    j. Usual method and periods of spilling water

B. Location, considering

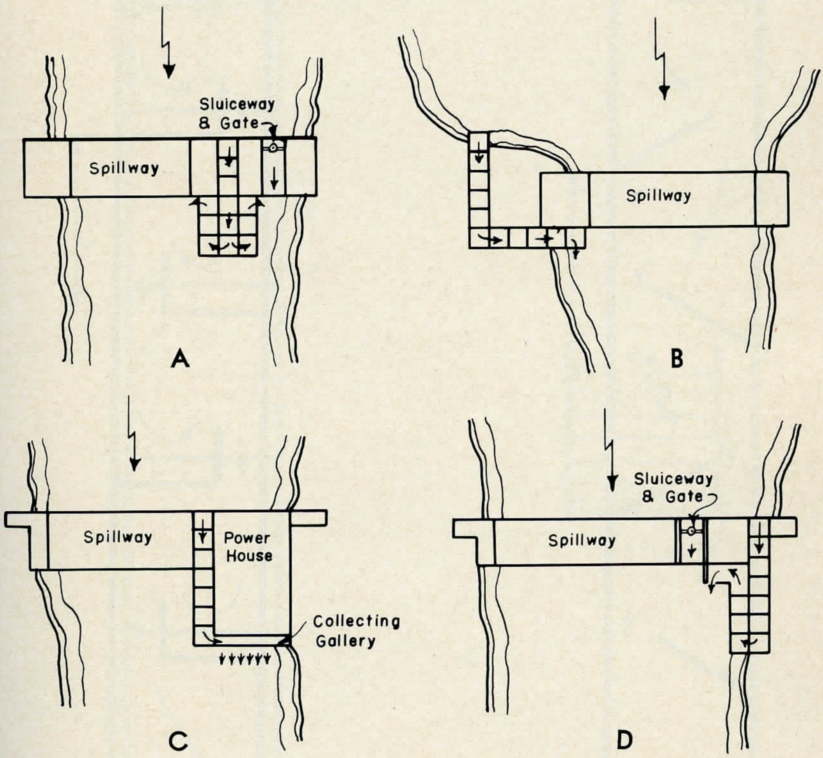
1. Flow of stream and position of obstruction
2. Point of probable fish concentration
3. Effect of fishway on operation of dam
4. Accessibility for construction and maintenance
5. Protection from ice, logs and vandalism
6. Cost

C. Design of Fishway

1. High, low and normal headwater elevations at fishway exit

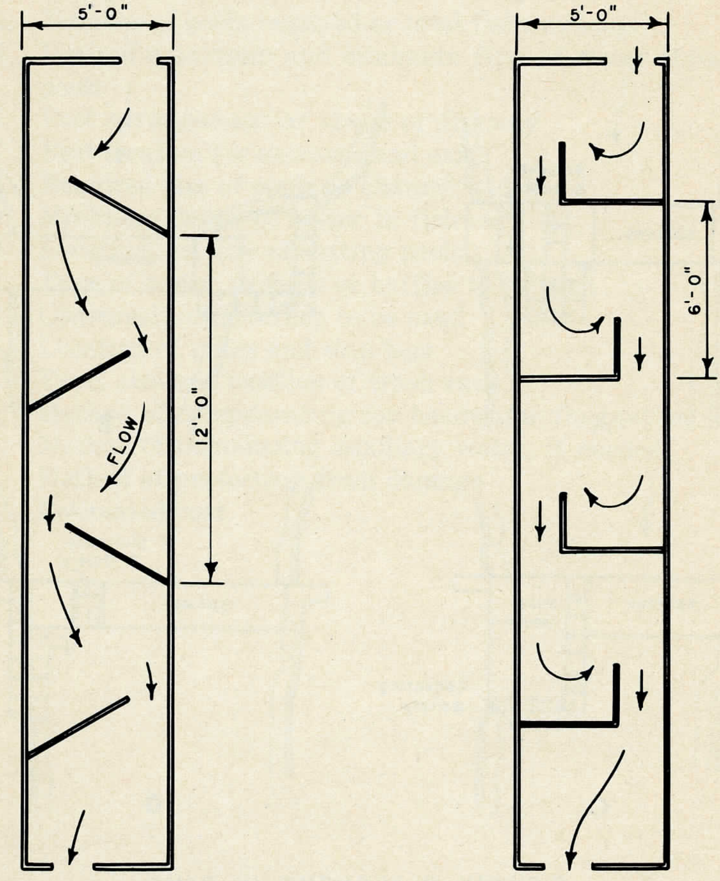
2. High, low and normal tailwater elevations at fishway entrance
3. Desired maximum and minimum drop per pool or fishway gradient
4. Number of pools required or total fishway length
5. Desired maximum and minimum flow of water through pools
6. Best arrangement or shape of fishway
7. Best location for entrance and exit
8. Required size of pools or channel width
9. Minimum depth of water in fishway
10. Location and size of resting pools
11. Type of weirs, orifices or baffles to be used
12. Construction materials to be used
13. Location of gates and stop logs
14. Type, size and location of trash rack
15. Method of compensating for headwater fluctuation
16. Method of introducing auxiliary water, if needed
17. Method of protecting from damage
18. Estimated cost

APPENDIX C



FISHWAY PLACEMENT IN DAMS

FIGURE NO. I

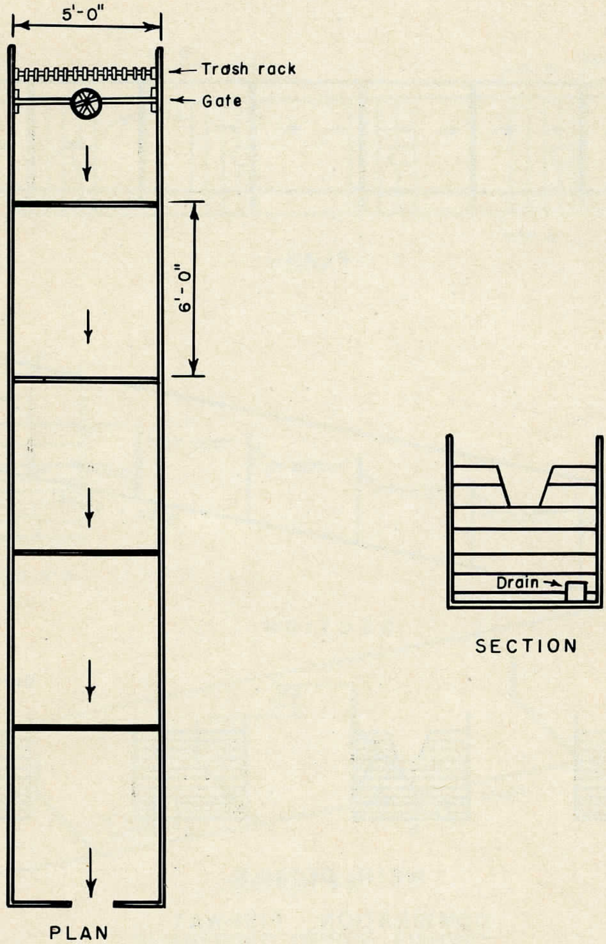


FOSTER TYPE
A

HOOK TYPE
B

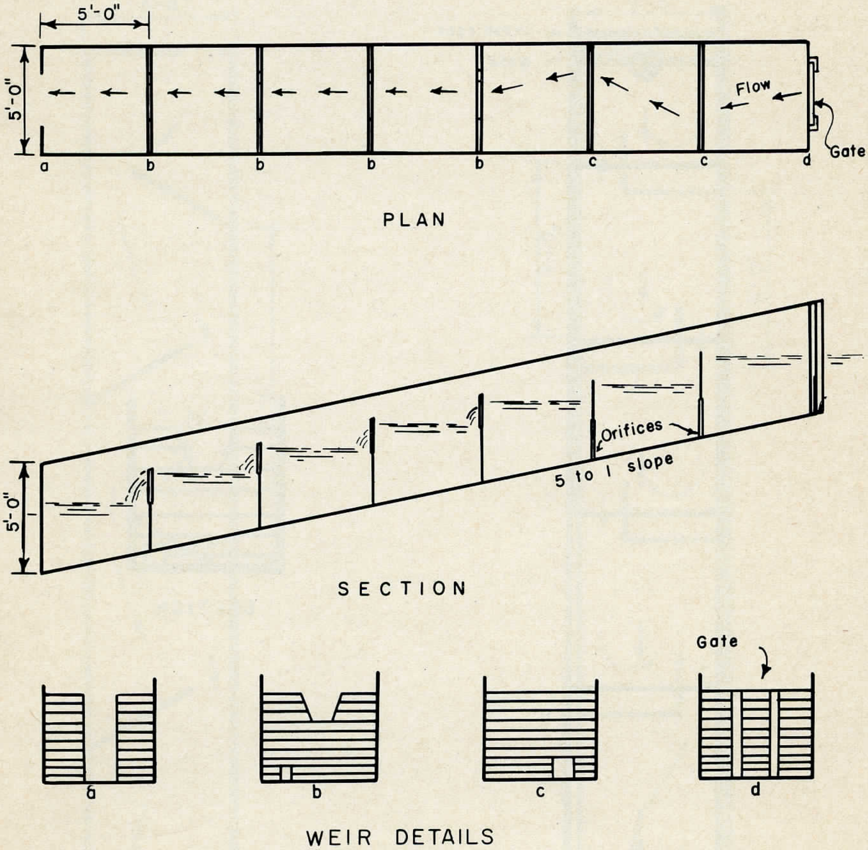
PLAN VIEWS OF EARLY FISHWAYS

FIGURE NO. 2



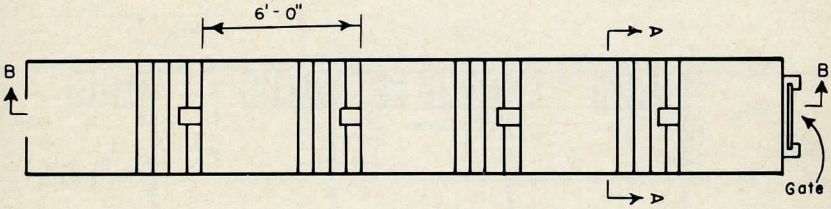
POOL TYPE FISHWAY WITH
NOTCHED WEIRS

FIGURE NO. 3



COMBINATION FISHWAY

FIGURE NO. 4



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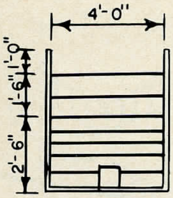
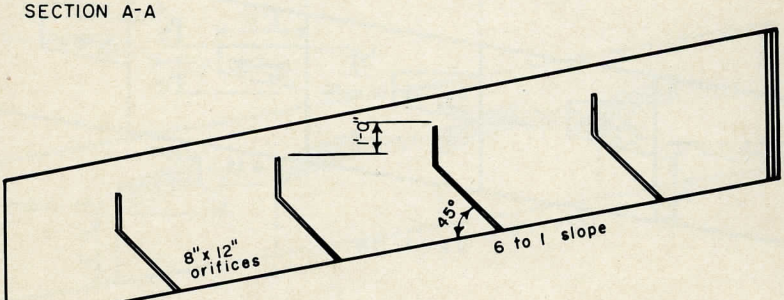


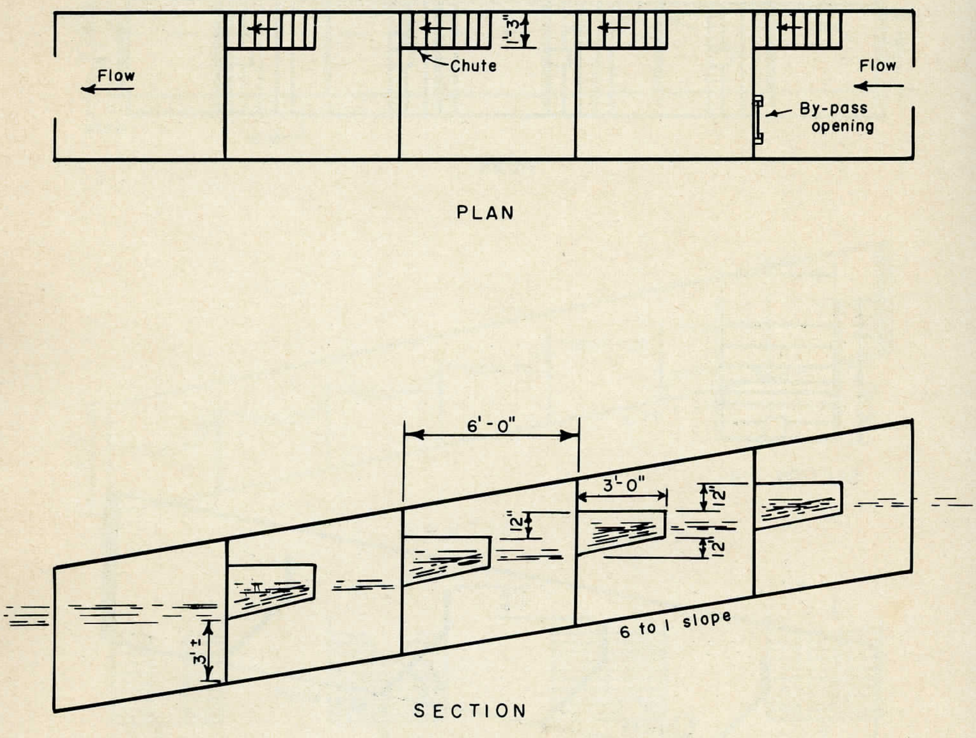
SECTION A-A



SECTION B-B

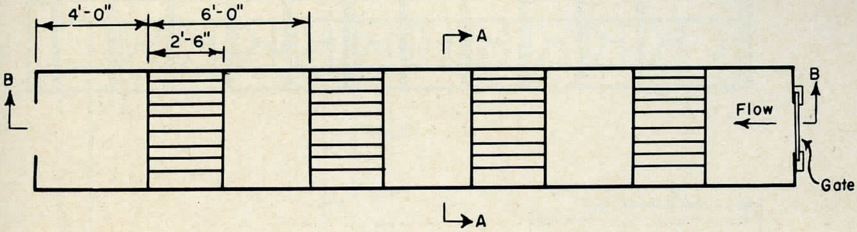
SUBMERGED ORIFICE FISHWAY

FIGURE NO. 5

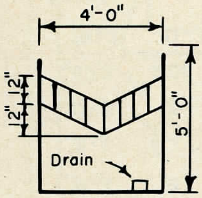


CHUTE TYPE FISHWAY

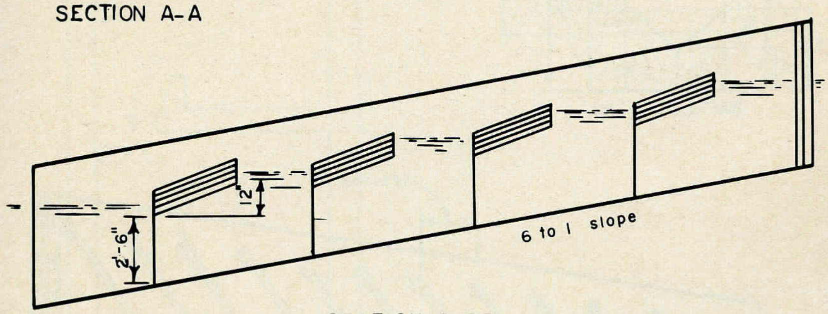
FIGURE NO. 6



PLAN



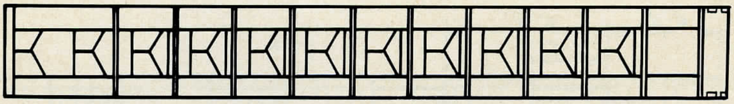
SECTION A-A



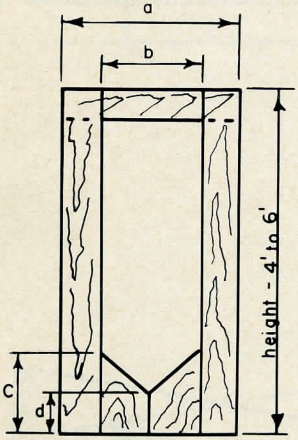
SECTION B-B

POOL TYPE FISHWAY WITH BUTTERFLY WEIR

FIGURE NO. 7

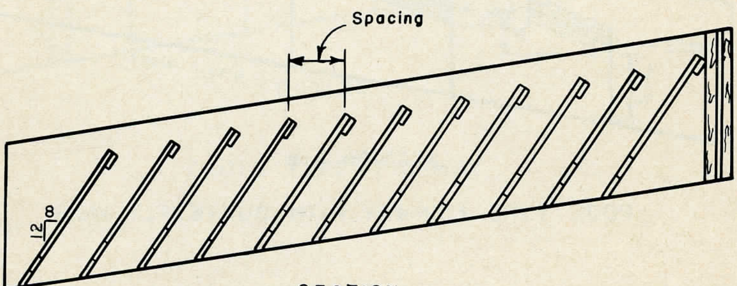


PLAN



BAFFLE DETAIL

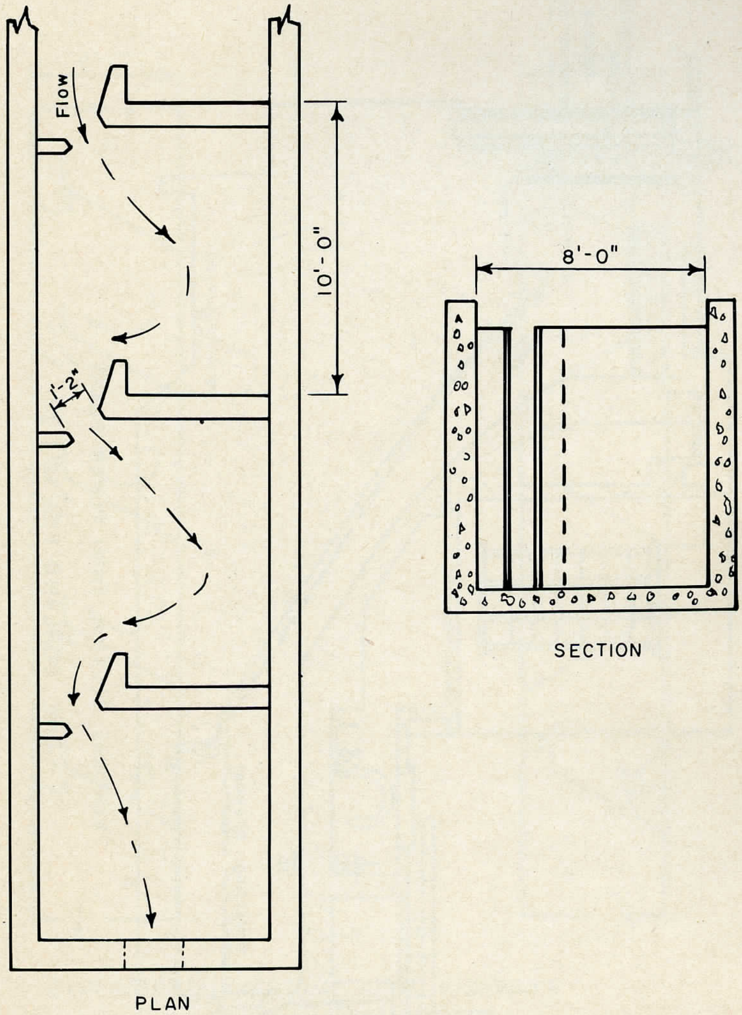
a	b	c	d	Spacing
4'-0"	2'-4"	2'-0"	1'-0"	2'-8"
3'-6"	2'-0"	1'-9"	$10\frac{1}{2}$"	2'-4"
3'-0"	1'-9"	1'-6"	9"	2'-0"
2'-6"	1'-5 $\frac{1}{2}$"	1'-3"	7 $\frac{1}{2}$"	1'-8"
2'-0"	1'-2"	1'-0"	6"	1'-6"



SECTION

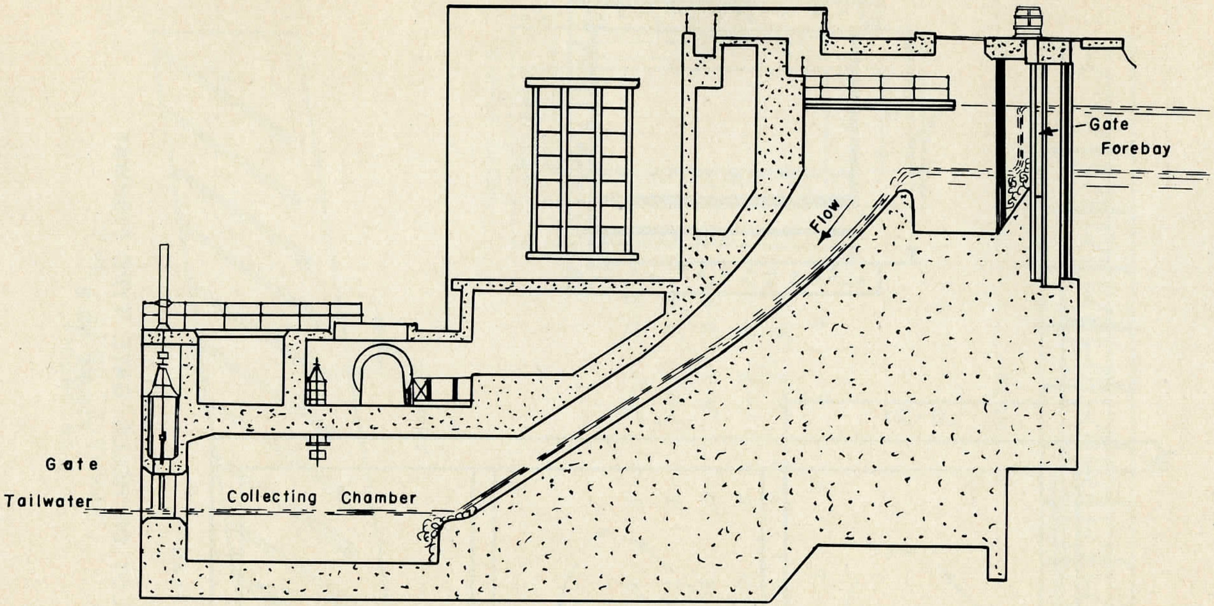
THE DENIL FISHWAY

FIGURE NO. 8



VERTICAL SLOT OR HELLS GATE TYPE FISHWAY

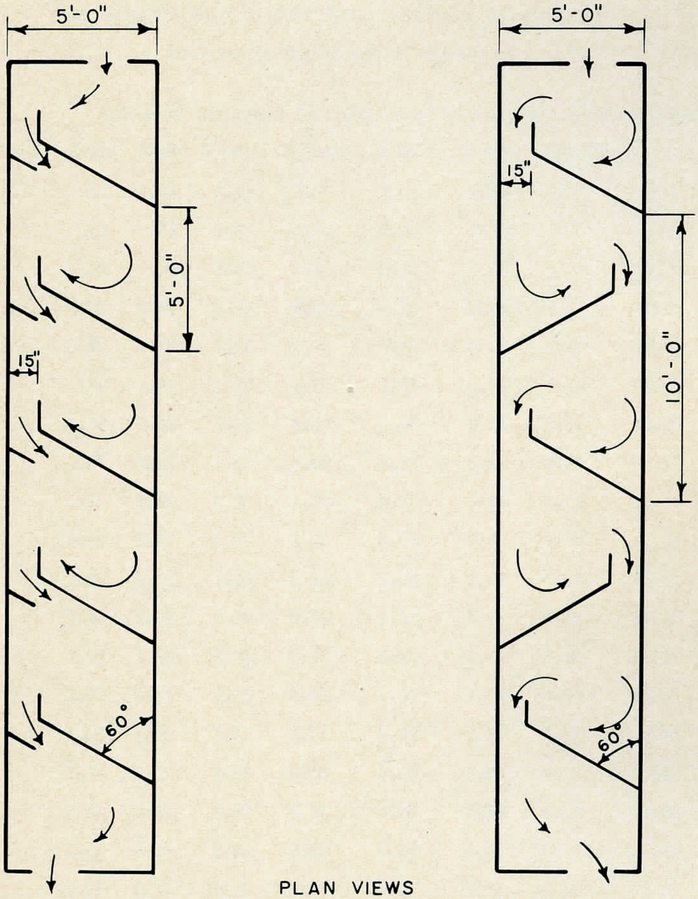
FIGURE NO. 9



VERTICAL SECTION THRU POWER PLANT

THE BORLAND FISH LIFT

FIGURE NO. 10



PLAN VIEWS

EXPERIMENTAL VERTICAL SLOT FISHWAYS

FIGURE NO. 11

APPENDIX D

Table 1

FLOW OF WATER THROUGH SHARP EDGED SUBMERGED ORIFICES WITH

CONTRACTION SUPPRESSED AT BOTTOM

	Volume of Discharge (cu. ft./sec.) for Orifices of Sizes Indicated							
Head (in.)	6"x6"	6"x8"	8"x10"	10"x12"	12"x12"	12"x15"	12"x18"	18"x24"
2	.51	.68	1.13	1.70	2.04	2.56	3.07	6.14
3	.62	.83	1.39	2.08	2.50	3.12	3.75	7.50
4	.72	.96	1.60	2.40	2.38	3.60	4.33	8.66
5	.81	1.07	1.79	2.68	4.22	4.03	4.84	9.68
6	.88	1.18	1.96	2.94	3.54	4.41	5.30	10.60
7	.95	1.27	2.12	3.18	3.82	4.77	5.73	11.46
8	1.02	1.36	2.27	3.40	4.08	5.11	6.12	12.25
9	1.08	1.44	2.40	3.60	4.33	5.41	6.49	12.98
10	1.14	1.52	2.54	3.80	4.56	5.71	6.85	13.70
11	1.20	1.59	2.65	3.98	4.78	5.98	7.18	14.35
12	1.25	1.67	2.78	4.16	5.00	6.25	7.50	15.00
13	1.30	1.73	2.88	4.33	5.20	6.50	7.80	15.60
14	1.35	1.80	3.00	4.50	5.40	6.75	8.10	16.20
15	1.40	1.87	3.11	4.66	5.60	7.00	8.40	16.80
16	1.45	1.93	3.21	4.81	5.75	7.22	8.67	17.34
18	1.54	2.05	3.41	5.12	6.15	7.69	9.22	18.45
20	1.61	2.15	3.58	5.37	6.45	8.06	9.68	19.35
22	1.69	2.25	3.75	5.62	6.75	8.44	10.12	20.25
24	1.77	2.35	3.91	5.87	7.05	8.81	10.60	21.20

The tabular values are obtained from the formula:

$Q = CA\sqrt{2gH}$ or $5A\sqrt{H}$ when $C = 0.625$ and $g = 32$.
Q = discharge in cubic feet per second
A = area in sq. ft. H = head in feet

The above volumes should be increased 50% for rounded edged orifices.
1 cu. ft./sec. = 449 gal./minute
2.31 ft. of water = 1 lb./sq. in.

Note: These flows are computed for orifices having the bottom of their openings at floor level.

Table 2

DISCHARGE IN CU. FT./SEC. FOR RECTANGULAR WEIRS WITH COMPLETE CONTRACTION

Head (in.)	1'	1.5'	2'	3'	Length of Crest 4'	5'	6'	Each Added Ft.
1"	.08	.12	.16	.24	.32	.40	.48	.08
1 1/2	.14	.21	.30	.44	.60	.76	.88	.15
2	.22	.32	.45	.67	.90	1.13	1.33	.23
2 1/2	.31	.47	.63	.95	1.28	1.57	1.91	.32
3	.40	.61	.82	1.23	1.65	2.06	2.48	.42
3 1/2	.50	.76	1.02	1.53	2.05	2.60	3.09	.53
4	.62	.94	1.25	1.90	2.54	3.18	3.83	.64
4 1/2	.73	1.10	1.48	2.24	3.00	3.78	4.53	.77
5	.84	1.28	1.72	2.60	3.48	4.43	5.26	.90
5 1/2	.99	1.49	2.00	3.03	4.05	5.09	6.14	1.04
6	1.11	1.68	2.26	3.42	4.58	5.80	6.95	1.18
7	1.40	2.12	2.84	4.31	5.77	7.27	8.76	1.49
8	1.69	2.56	3.43	5.20	6.97	8.82	10.6	1.81
9	2.01	3.05	4.10	6.21	8.33	10.5	12.7	2.16
10	2.35	3.57	4.79	7.27	9.75	12.2	14.8	2.53
11	2.69	4.08	5.48	8.31	11.15	14.2	16.9	2.94
12	3.06	4.64	6.25	9.48	12.7	16.0	19.3	3.33
13		5.23	7.04	10.7	14.3	17.8	21.7	3.70
14		5.80	7.81	11.8	15.9	20.0	24.1	4.20
15		6.43	8.66	13.1	17.6	22.2	26.8	4.66
16				14.5	19.4	24.3	29.4	5.13
17				15.8	21.2	26.7	32.0	5.62
18				17.2	23.1	28.8	34.9	6.12

The tabular values are obtained from the formula:

$Q = 3.33\ (L - 0.2H)\ H^{1.5}$ in which L = length of crest in feet
H = head at crest in feet

Note: With complete contraction the width of the weir is less than the width of the channel, the edge of the weir being at least 2.5 H from the sides of the channel.

Table 3

DISCHARGE IN GALLONS PER MINUTE FOR STANDARD SUPPRESSED RECTANGULAR WEIR

	Length of Crest						
Head (inches)	1'	1.5'	2'	3'	4'	5'	6'
1	35.8	53.8	71.7	107	143	179	215
1 1/4	50.2	75.4	100	150	201	251	302
1 1/2	65.5	98.8	131	197	263	330	395
1 3/4	83.3	125	166	250	334	416	512
2	101	152	206	305	411	507	610
2 1/4	121	182	243	364	484	606	727
2 1/2	142	213	285	426	568	709	853
2 3/4	164	246	327	492	655	817	983
3	187	280	375	561	750	934	1122
3 1/2	236	354	471	709	947	1180	1420
4	286	431	579	862	1148	1435	1720
4 1/2	344	516	686	1032	1373	1718	2065
5	401	601	803	1206	1606	2010	2420
5 1/2	463	696	911	1391	1853	2315	2780
6	529	794	1059	1584	2112	2640	3175
6 1/2	596	893	1189	1785	2400	2980	3580
7	665	997	1328	1992	2660	3320	3990
7 1/2	739	1108	1476	2218	2960	3700	4440
8	815	1220	1629	2440	3260	4070	4890

The tabular values are obtained from the formula:

$Q = 1494.5LH^{1.5}$ in which Q = discharge in gallons per minute
H = head at crest in feet
L = length of crest in feet

Note: A weir has its end contraction suppressed if the length of its crest is the same as the channel width.

Table 4

FLOW OF WATER IN CU. FT./SEC. THROUGH CIPOLETTI WEIRS

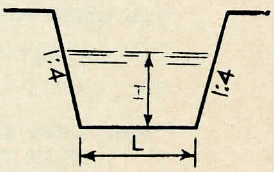
Head (in.)	Head (ft.)	12" Weir	15" Weir	18" Weir	24" Weir
1	.0833	.08	.10	.12	.16
2	.1667	.23	.29	.34	.46
3	.2500	.42	.53	.63	.84
4	.3333	.65	.81	.97	1.29
5	.4167	.90	1.13	1.36	1.81
6	.5000	1.19	1.49	1.79	2.38
7	.5833	1.50	1.87	2.25	3.00
8	.6667	1.83	2.29	2.75	3.66
9	.7500	2.19	2.73	3.28	4.37
10	.8333	2.56	3.20	3.84	5.12
11	.9167	2.96	3.70	4.43	5.91
12	1.000	3.37	4.21	5.05	6.73
13	1.083	3.80	4.74	5.69	7.59
14	1.167	4.24	5.31	6.36	8.48
15	1.250	4.70	5.88	7.06	9.41
16	1.333	5.18	6.48	7.78	10.36
17	1.417	5.68	7.11	8.52	11.35
18	1.500	6.18	7.73	9.28	12.37

The tabular values are obtained from the formula:

$Q = 3.367LH^{1.5}$ in which

L = length of crest in feet

H = head in feet



CIPOLETTI WEIR

Table 5

		FACTORS OF H			FLOW OF WATER IN CFS THROUGH V-NOTCH WEIRS	
Head (in.)	Head (ft.)	$H^{0.5}$	$H^{1.5}$	$H^{2.5}$	90° Weir	60° Weir
1"	.0833'	.289	.024	.002	.0050	.0029
1 1/2	.1250	.354	.044	.0055	.0138	.0079
2	.1667	.409	.068	.011	.0275	.0159
2 1/2	.2083	.456	.095	.020	.050	.029
3	.2500	.500	.125	.031	.078	.044
3 1/2	.2917	.540	.158	.046	.115	.066
4	.3333	.577	.192	.064	.160	.092
4 1/2	.3750	.612	.230	.0861	.215	.124
5	.4167	.645	.269	.112	.280	.162
5 1/2	.4583	.677	.310	.142	.355	.205
6	.5000	.707	.354	.177	.442	.255
7	.5833	.764	.445	.260	.650	.375
8	.6667	.817	.545	.363	.908	.524
9	.7500	.866	.650	.487	1.22	.703
10	.8333	.913	.760	.633	1.58	.913
11	.9167	.957	.878	.805	2.01	1.16
12	1.000	1.00	1.00	1.00	2.50	1.44
13	1.083	1.04	1.13	1.22	3.05	1.76
14	1.167	1.08	1.26	1.47	3.68	2.12
15	1.250	1.12	1.40	1.75	4.38	2.52
16	1.333	1.15	1.54	2.05	5.12	2.96
17	1.417	1.19	1.69	2.39	5.98	3.45
18	1.500	1.23	1.84	2.76	6.90	3.98

The general formula for the V-notch weir is: $Q = 2.5 \tan \frac{1}{2} \varnothing\ H^{2.5}$

For 90° weir: $Q = 2.5\ H^{2.5}$, and for 60° weir: $Q = 1.443\ H^{2.5}$